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TECHNICAL REPORT 3468

EVALUATION OF VARIOUS GRADES OF MALLEABLE IRON FOR THE 2.75-INCH M151 ROCKET WARHEAD (U)

EDWARD A. KRAJKOWSKI
RAY S. JOHNSON

OCTOBER 1966

U.S. ARMY MUNITIONS COMMAND

PICATINNY ARSENAL
DOVER, NEW JERSEY

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(C) SUMMARY

(U) To broaden the procurement base of the 2.75-Inch M151 Rocket Warhead, ferritic malleable iron (FMI) was evaluated for its suitability as an alternate material to pearlitic malleable iron (PMI). Based on successful safety and effectiveness testing, FMI was incorporated into the Technical Data Package (TDP) for the M151 Warhead as an alternate material for the nose casting.

(C) Also, to reduce acceptance testing costs of nose castings, several grades of PMI were surveyed to determine the effect of matrix structure on effectiveness. No significant differences were discernible.

(U) This program was conducted by the Ammunition Engineering Directorate's Ammunition Engineering Laboratory from November 1965 to June 1966.

(C) CONCLUSIONS

(U) FMI (tensile strength 48,000 psi minimum; yield strength 28,000 psi minimum at 0.2% offset; elongation 10% minimum) is safe for use as a substitute material for the nose of the M151 Warhead.

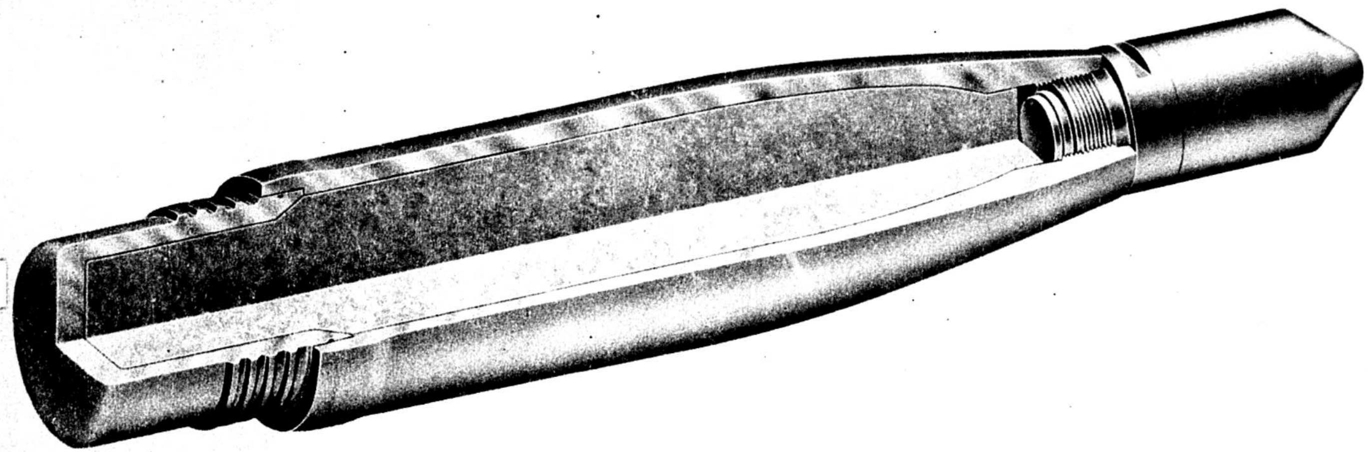
(C) Lethal effectiveness of FMI is at least 95% that of 60003 PMI.

(C) Variations in matrix structure of PMI do not significantly affect safety or lethal effectiveness of the M151 Warhead.

(U) RECOMMENDATIONS

FMI is an acceptable alternate material for the nose of the M151 Warhead.

A sampling plan for Brinell hardness testing should be substituted for the 100% testing now required for malleable iron.



WARHEAD, 2.75 IN. ROCKET, H. E.: M151
WITH FUZE, ROCKET: M423 OR XM427E1

(U) BACKGROUND

The 2.75-Inch M151 Rocket Warhead is an air-to-ground fragmentation munition used in fixed and rotary-wing aircraft against personnel and light materiel targets. It consists of a cast iron nose brazed to a steel or cast iron base and it is loaded with Composition B4. The Mk 40 Motor provides propulsion and the M423 or XM427E1 Fuzes provide initiation.

The M151 Warhead was developed by Picatinny Arsenal to increase the lethality of the existing Navy Mk 1 Warhead and adapt the 2.75-Inch Rocket for an air-to-ground anti-personnel role. This was accomplished by lengthening the warhead, changing the casing material and explosive filler. Limited Production approval was received in November 1964. Engineer/Service Test (ET/ST) was performed in 1965 and Type Classification as Standard A was obtained in November 1965.

The material originally specified for the nose portion of the warhead was PMI. Difficulty in obtaining available foundry capacity for this material led to a search for other suitable substitutions. Several grades of ductile (nodular) iron were evaluated for suitability as alternate materials. Grade 60-45-10 was incorporated as an acceptable alternate in August 1965 (Reference 4).

Further broadening of the supply base was desired -- especially if a cost saving could be realized. Towards this goal, FMI was investigated.

Reduction of acceptance testing costs of PMI castings also was desired. If effectiveness is independent of matrix, the 100% Brinell hardness testing requirement can be eliminated. Several grades of PMI were tested to determine if this hardness criterion could be deleted.

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(C) STUDY

(U) To broaden the supply base -- with particular emphasis on reducing cost -- for the M151 Warhead, the U.S. Army Materials Research Agency (AMRA) at Watertown, Massachusetts, was funded by Picatinny Arsenal to supply samples of FMI for initial evaluation. Favorable results of effectiveness and safety tests would permit incorporation of FMI as an alternate material.

(U) A backlog of work at AMRA precluded immediate fabrication of a sufficient number of FMI warheads for evaluation. Texas Foundry of Lufkin, Texas, substituted a quantity of FMI castings for PMI castings. A total of 267 warheads were shipped to Picatinny Arsenal for testing and evaluation.

(U) FMI differs from PMI in its matrix structure. Its manufacture is similar except for the heat treatment. Both FMI and PMI are usually melted using a duplex process: a cupula to melt and an air or electric furnace to superheat, homogenize and refine composition. The furnace is tapped which the test plug is white iron -- most of the carbon is in the combined form as iron carbide. A typical composition for both is: 2.30 to 2.40% C; 1.45 to 1.55% Si; 0.42 to 0.48% Mn; 0.15% S, 0.03% P. Heat treatment must now be performed to convert all the combined carbon into elemental carbon (graphite) and ferrite if FMI is desired. This process is done in two steps called "first and second stage annealing." During the first stage (done in the gamma range), all massive carbides are broken down and equilibrium is established between iron and carbon for the particular holding temperature employed. During the second stage (done within or just below the eutectoid or critical temperature range), the last few hundredths of 1% of carbon remaining in solution in the austenite (or ferrite) are precipitated as graphite on the nodules formed during the first stage. The process converts the white iron into compact graphite agglomerates in a tough ferritic matrix.

(U) PMI contains purposely retained eutectoidal carbides or low temperature transformation products. The pearlitic structure may be secured in any of several ways:

1. Arrested anneal, which is most commonly used, halts graphitization in quenching followed generally by tempering.

2. Heat treatment of completely graphitized ferritic malleable iron.

3. Retarding second stage graphitization by adding a suitable alloy, through quenching and re-heat treatment or through a combination of alloy and quench (Reference 1).

(C) Sample warheads fabricated with FMI noses cast at Texas Foundry and machined at Frankford Arsenal were subjected to Drop and Pit Fragmentation Tests at Picatinny Arsenal. The data are in Tables 1-3. An evaluation of these data is in Figure 2 and is compared to an ideal band representing Mott distributions for average fragment mass ($\bar{m}$) considered optimum for prone and standing targets. A similar evaluation for 60003 PMI is in Figure 3. Figure 1 shows input data used to obtain optimum $\bar{m}$ for prone and standing targets. Mott distributions for $\bar{m}$ - 2 (prone optimum) and $\bar{m}$ -4 (standing optimum are also shown). The comparison shows 32510 FMI to be worth further investigation.

(U) Warheads were received for safety and effectiveness testing. Physical properties and a typical microstructure are in Table 4. Test Program Requests were sent to the U.S. Army Test & Evaluation Command (TECOM) requesting Ballistic Research Laboratories (BRL) box tests and lethal analysis on five FMI rounds and a series of safety tests (5- and 40-Foot Drop Tests, Jolt and Jumble Tests, 3-Day Temperature Storage and firing from a ground launcher).

(C) The workload at BRL precluded an immediate lethality analysis; therefore, four rounds were fragmented at APG and lethal areas were derived from this data by the Ammunition Engineering Directorate's Warheads & Special Projects Laboratory. The input parameters to the lethal program were:

Military stress situation	:	5-Minute Assault (per BRL 1269)
Burst height	:	Ground burst
Orientation angles	:	2°, 5°, 10°, 20°, 30°, 40°
Target posture	:	Prone and standing men
Shape factor	:	A/M - Ca $M^{-1/3}$

Type	Ca(ft^2/lb) $gr^{1/3}$
FMI	0.6009
PMI	0.568

Scale factor: for PMI 1.159
for PMI 1.00

The results indicated that the lethal areas of the FMI round are within 5% of the PMI round and that the FMI version could serve as an acceptable substitute (Reference 2). These results are compared to 60003 PMI in Table 5.

(U) The safety test series agreed to by Picatinny Arsenal and APG was run concurrently with the effectiveness tests. The FMI warhead passed all tests -- there were no UNSAFE conditions. APG and TECOM concluded that FMI is a suitable substitute material for PMI in the M151 Warhead (Reference 3). A summary of these tests is outlined:

Test	Method	Sample Size (°F)	Results
5-Foot Drop (Fired)	MIL-STD-358 (unpackaged)	5 @ -65	All
40-Foot Drop	MIL-STD-302	20 (4 in box) @ -65	Tests
Jolt (Fired)	MIL-STD-300	10 @ ambient	Were
Jumble (Fired)	MIL-STD-301	10 @ ambient	Satisfactory
3-Day Temperature Storage (Fired)	OPM-10-100	14 @ -65 14 @ +155	

(U) FMI was incorporated into the TDP by Engineering Order 42853 dated 8 June 1966, to be applied to current and future contracts. Picatinny Arsenal suggested that a substantial cost savings could be negotiated on the basis of this change. To obviate the possibility of losing all sources of PMI then discovering an unforeseen problem with FMI, the Project Manager for 2.75-Inch Rocket directed that initially no more than 50% of the PMI being manufactured switch to FMI. After a few months of successful production, the balance would switch if the contractors so desired.

(U) To reduce the acceptance testing costs of PMI castings it was necessary to determine whether effectiveness is degraded if physical properties (determined by matrix structure) are other than those specified by the production grade 60003. If effectiveness is independent of matrix, the 100% Brinell hardness testing requirement could be eliminated.

(U) Samples of these grades were fabricated at AMRA: 80002, 50007 and 45010. Physical properties and chemical analysis of these grades and of Grade 60003 are in Table 6. Representative microstructures from nose fragments are in Figures 8-10.

(U) Two samples of each grade were pit fragmented at Picatinny Arsenal. Results are in Tables 1-3.

(C) Analysis of the PMI fragmentation data is in Figures 4-7. Although Grade 50007 and 80002 do not follow the ideal distribution exactly, they closely approach this distribution in the 0.5- to 20-grain fragment weight range. Fragments less than 0.5-grain are considered ineffective and those that exceed 20 grains are considered inefficient.

(U) Drop tests (5 feet @ -65°F and 40 feet @ ambient) were successfully conducted on each of the PMI grades.

(U) A recommendation was made to replace the 100% Brinell testing with a sampling plan.

(U) REFERENCES

1. Malleable Iron Castings, Malleable Founders Society, The Ann Arbor Press Inc., Ann Arbor, Michigan, 1960.

2. Thomas Heuter, Evaluation of XM151 2.75-Inch Warhead (Ferritic Malleable Cast Iron-FMCI) Warheads & Special Projects Laboratory Letter Report to Ammunition Engineering Laboratory, Picatinny Arsenal, May 1966.

3. Engineering Test (Safety Release) for Warhead, 2.75-Inch Rocket, HE, M151 (Ferritic Malleable Iron), Firing Record R-3682, Aberdeen Proving Ground, Maryland, May 1966.

4. Edward A. Krajkowski, Evaluation of Various Grades of Nodular Graphitic Iron for the 2.75-Inch M151 Rocket Warhead, Picatinny Arsenal Technical Report 3342, April 1966.

APPENDICES

APPENDIX A

Tables

(C) TABLE 1

PIT FRAGMENTATION RESULTS - NUMBER OF FRAGMENTS (U)

Weight Group	PMI 80002 Round 1	PMI 80002 Round 2	PMI 60003 Round 3	PMI 60003 Round 4	PMI 50007 Round 5	PMI 50007 Round 6	PMI 45010 Round 7	PMI 45010 Round 8	FMI 32510 Round 9	FMI 32510 Round 10
0.5-0.8	1,739	2,029	1,545	1,997	2,147	2,363	1,441	1,641	1,483	1,760
0.8-2	3,727	3,760	3,699	3,414	4,468	3,881	2,461	2,585	2,506	3,310
2-3	1,689	1,686	1,320	1,304	1,917	1,663	1,029	966	1,098	1,196
3-5	1,813	1,781	1,248	1,402	1,723	1,845	1,079	1,060	1,170	1,190
5-7	799	820	728	743	816	911	667	575	636	620
6-10	564	640	579	621	635	644	551	522	602	567
10-15	382	431	452	481	395	420	482	453	508	489
15-20	134	148	254	218	178	147	286	260	222	226
20-30	86	81	175	130	84	69	220	239	172	163
30-50	44	27	62	78	42	35	81	101	89	87
50-75	7	8	15	24	14	14	23	24	24	24
75-150	4	2	12	13	2	5	4	4	5	5
150-750	1	1	7	7	0	1	0	0	0	1
Total	10,989	11,414	10,096	10,450	12,421	11,997	8,304	8,430	8,515	9,638

(C) TABLE 2

PIT FRAGMENTATION RESULTS -- PERCENT BY WEIGHT (U)

Weight Group	PMI 80002		PMI 60003		PMI 50007		PMI 45010		PMI 32510	
	Round 1	Round 2	Round 3	Round 4	Round 5	Round 6	Round 7	Round 8	Round 9	Round 10
0.5-0.8	3.0	4.8	2.4	3.0	5.1	3.8	2.3	2.7	2.4	5.1
0.8-2	13.3	15.2	11.1	10.2	15.6	12.6	8.1	8.4	8.3	10.9
2-3	10.8	9.7	7.4	7.3	9.3	10.1	6.4	6.0	6.9	6.7
3-5	18.2	16.4	11.1	12.4	14.5	17.7	10.4	10.4	11.6	10.5
5-7	12.3	11.8	9.9	10.0	11.4	13.3	9.9	8.5	9.5	8.8
7-10	12.2	12.8	11.1	11.8	12.4	13.2	11.5	11.0	12.8	11.4
10-15	11.9	12.3	12.6	13.1	10.9	12.5	14.7	13.8	15.7	13.9
15-20	6.0	6.3	10.1	8.4	7.8	6.2	11.5	11.2	9.6	9.3
20-30	5.4	4.1	9.7	7.0	4.7	4.1	13.2	14.4	11.4	9.3
30-50	4.4	2.6	5.0	6.6	3.6	3.2	7.7	9.1	8.2	7.7
50-75	1.1	1.0	2.3	3.3	2.1	2.1	3.4	3.5	3.6	3.6
75-150	0.9	0.5	2.6	3.0	0.5	1.1	1.0	1.0	1.1	1.5
150-750	0.4	2.6	4.8	4.0	1.0	0.0	0.0	0.0	0.0	1.0

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(C) TABLE 3

PIT FRAGMENTATION RESULTS -- WEIGHT OF FRAGMENTS IN OUNCES (U)

Weight Group	Pearlitic Malleable 80002		Pearlitic Malleable 60003		Pearlitic Malleable 50007		Pearlitic Malleable 45000		Ferritic Malleable 32510	
	Round 1	Round 2	Round 3	Round 4	Round 5	Round 6	Round 7	Round 8	Round 9	Round 10
0-0.5	*	5.5	0.1	0.2	5.5	*	*	*	*	5.0
0.5-0.8	2.6	5.5	2.4	3.0	4.8	3.5	2.1	2.5	2.3	--
0.8-2	11.7	14.0	11.0	10.3	15.2	11.7	7.4	7.6	7.5	11.3
2 - 3	9.5	9.5	7.4	7.4	9.0	9.4	5.8	5.5	6.2	6.5
3 - 5	16.0	16.0	11.1	12.6	14.5	16.4	9.5	9.5	10.5	10.5
5 - 7	10.8	11.5	9.9	10.1	11.0	12.3	9.0	7.8	8.6	8.5
7 - 10	10.8	12.5	11.1	11.9	12.0	12.3	10.5	10.0	11.6	11.0
10-15	10.5	12.0	12.5	13.3	10.5	11.6	13.5	12.6	14.2	13.5
15-20	5.3	6.0	10.0	8.5	7.5	5.8	10.6	10.3	8.7	9.0
20-30	4.8	4.0	9.7	7.1	4.5	3.8	12.1	13.2	9.4	9.0
30-50	3.9	2.5	5.0	6.7	3.5	3.0	7.0	8.3	7.4	7.5
50-75	1.0	1.0	2.2	2.3	2.0	1.9	3.1	3.2	3.3	3.5
75-150	0.8	0.5	2.6	3.0	0.5	1.0	0.9	0.9	1.0	1.5
150-750	0.4	2.5	4.8	4.0	1.0	0	0	0	0	1.0
Total	5 lb. 8.1 oz.	6 lb. 8 oz.	6 lb. 3.8 oz.	6 lb. 4.4 oz.	6 lb. 5.5 oz.	5 lb. 9.4 oz.	5 lb. 11.5 oz.	5 lb. 11.5 oz.	5 lb. 10.7 oz.	6 lb. 6 oz.

* 0-0.5 range weight inaccurate

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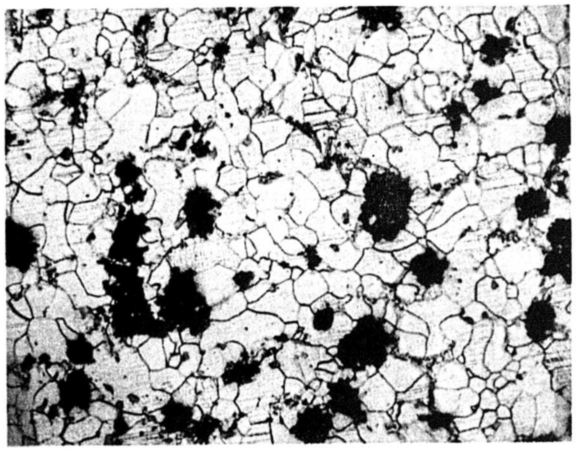
(U) TABLE 4

PHYSICAL PROPERTIES OF FERRITIC MALLEABLE IRON TESTED

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Yield Strength (psi)	32,200	32,800	30,400	29,800	29,200	29,700
Tensile Strength (psi)	51,200	51,600	49,200	49,200	49,700	48,600
Elongation (%)	14.8	17.5	14.4	15.6	----	---

Typical Microstruct~~ive~~ure



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(C) TABLE 5

LETHAL AREA RATIOS (U)

Orientation Angle (°)	Standing 60003 PMI	Standing 32510 FMI	Prone 60003 PMI	Prone 32510 FMI
2	1.00	0.97	1.00	0.98
5	1.00	0.96	1.00	0.96
10	1.00	0.95	1.00	0.97
15	1.00	0.96	1.00	0.98
20	1.00	0.98	1.00	0.97
30	1.00	0.99	1.00	0.98
40	1.00	0.98	1.00	1.00

(U) TABLE 6

PHYSICAL AND CHEMICAL PROPERTIES OF GRADES TESTED

Physical Properties Tested

Material	Tensile Strength (psi)	Yield Strength (psi)	Elongation (%)	Charpy (#)
80002 PMI	90/91,000	89,000	2.0	0.49
60003 PMI	80/82,000	65/72,000	3.0	0.99
50007 PMI	69/82,500	64/68,500	5.2/5.6	1.32
45010 PMI	48/55,700	31,36,000	13/21	1.89

Chemical Analysis

Material	Carbon %C	Silicon %S	Manganese %Mn	Sulfur %S	Phosphorous %P	Chromium %Cr
80002	2.5	1.2	1.1	0.11	0.10	0.05
60003	2.5	1.1	1.2	0.11	0.09	0.04
50007	2.5	1.1	1.1	0.12	0.08	0.03
45010	2.5	1.0	1.3	0.09	0.10	0.05
32510	2.0	1.2	0.6	0.11	0.012	0.02

APPENDIX B

Figures

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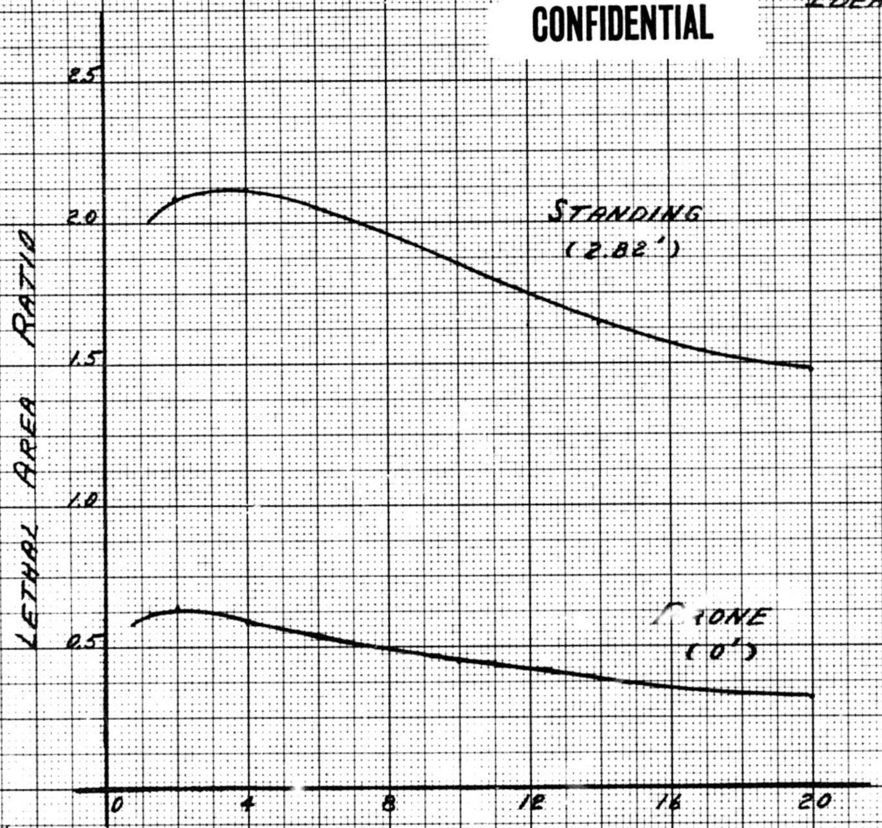

IDEAL FRAGMENTATION ANALYSIS

DATA

FIVE MINUTE ASSAULT

TERMINAL VELOCITY 1600 FT/SEC.

INITIAL VELOCITY 4800 FT/SEC.

ANGLE OF FALL 6°

SIDE SPRAY 80° TO 100°

METAL WEIGHT 6.3 #

EXPLOSIVE WEIGHT 2.3 #

MOTT DISTRIBUTION

RANGE	$\bar{m}=2$	$\bar{m}=4$
.0-.5	11177	4340
.5-1.0	2760	1250
1.0-2.0	2751	1380
2.0-5.0	3004	1787
5.0-10	1423	1089
10-20	681	711
20-25	103	145
25-50	130	247
50-75	15	50
75-150	3.72	22
150-750	.11	1.9
750-2500	0	0

AVERAGE FRAGMENT MASS IN GRAINS (u)

(C) FIGURE 1

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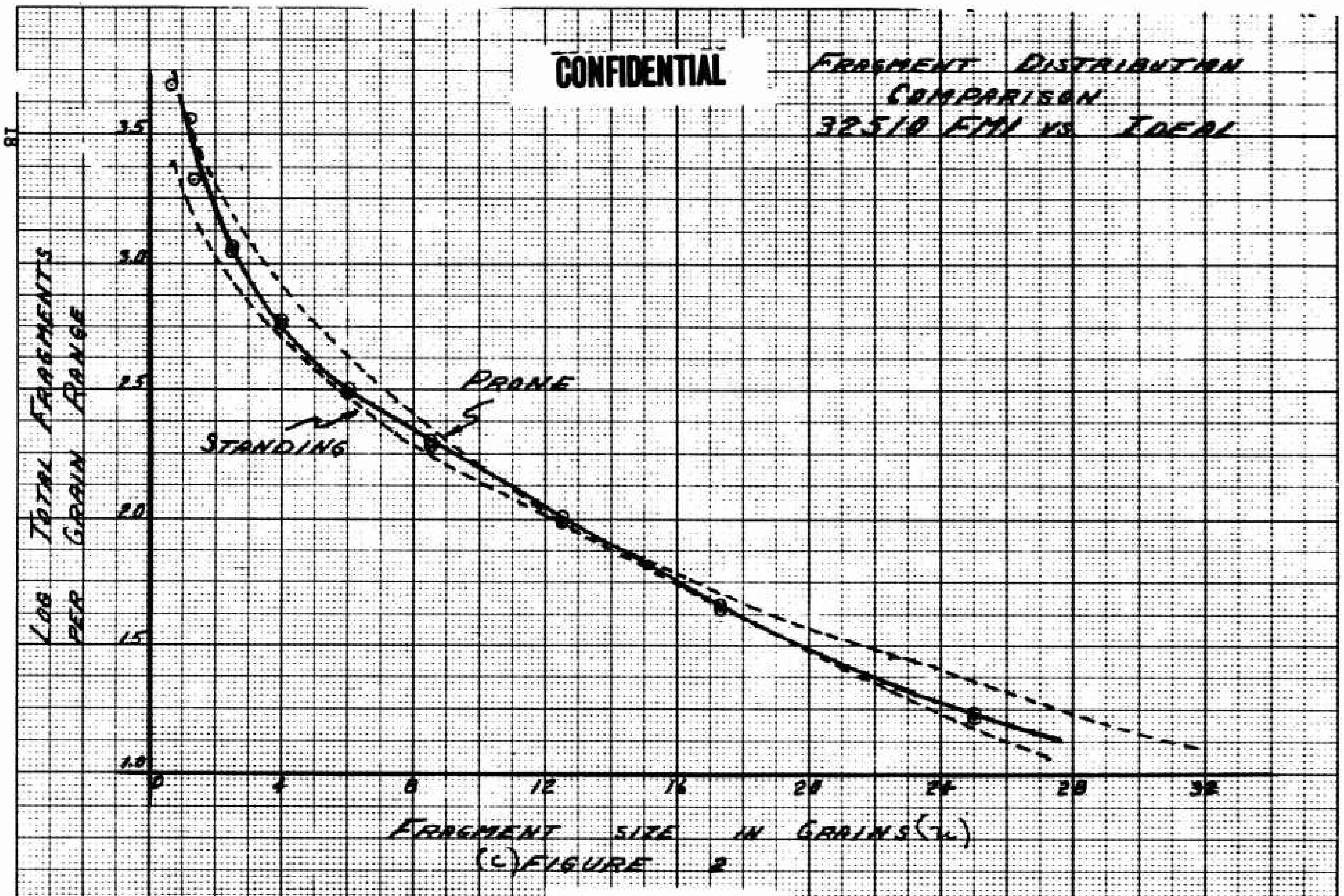

(C) FIGURE 2

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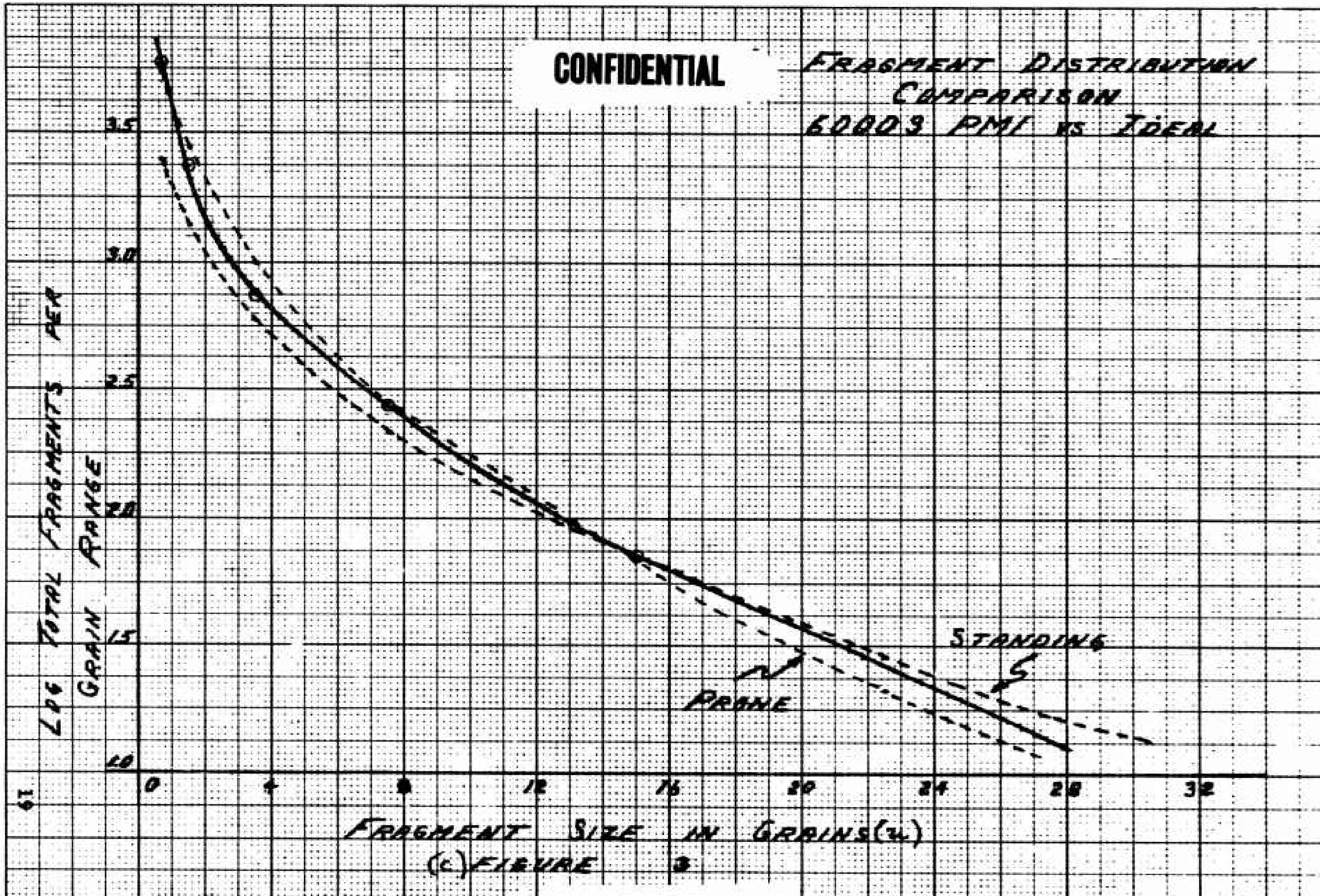

(c) FIGURE 3

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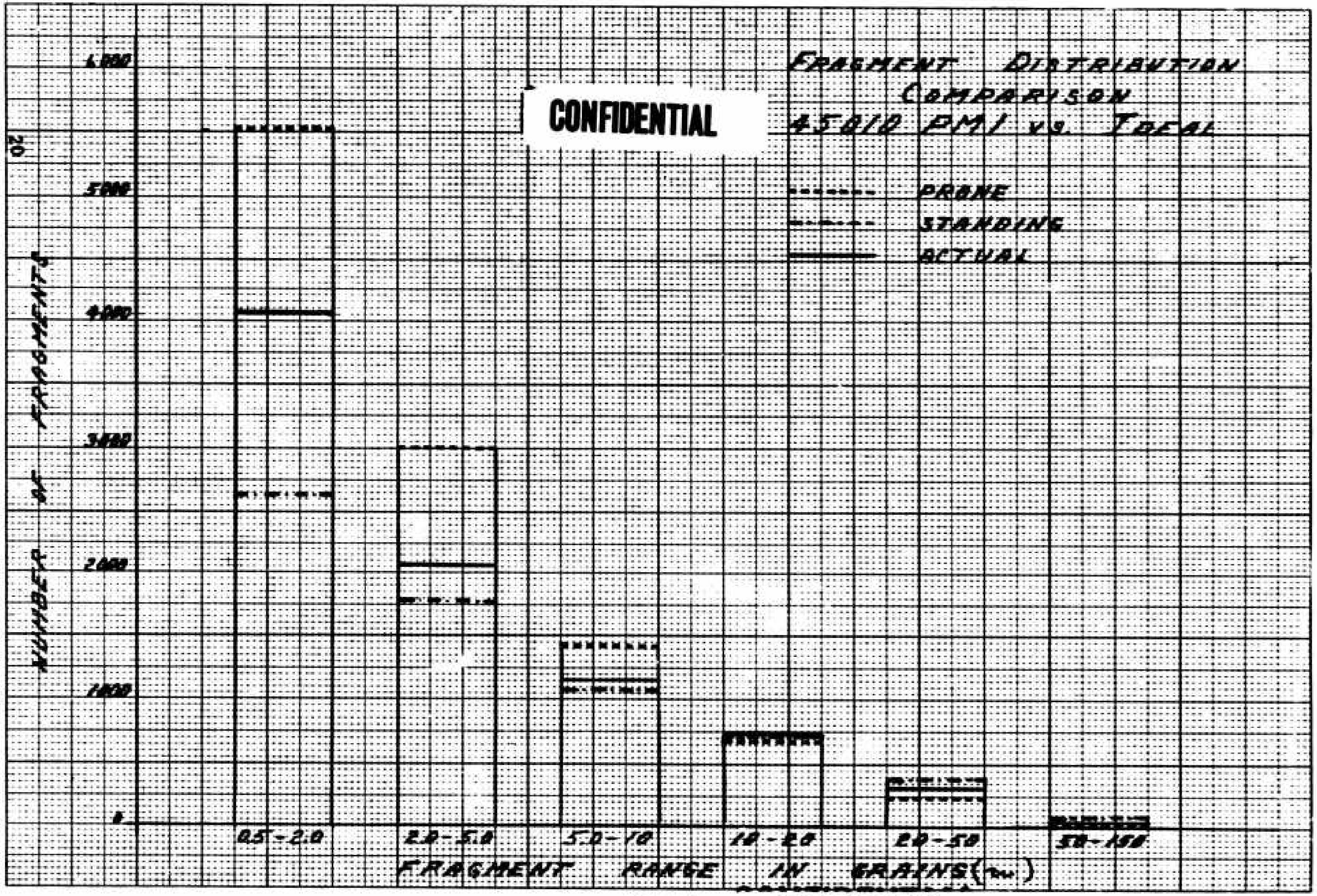
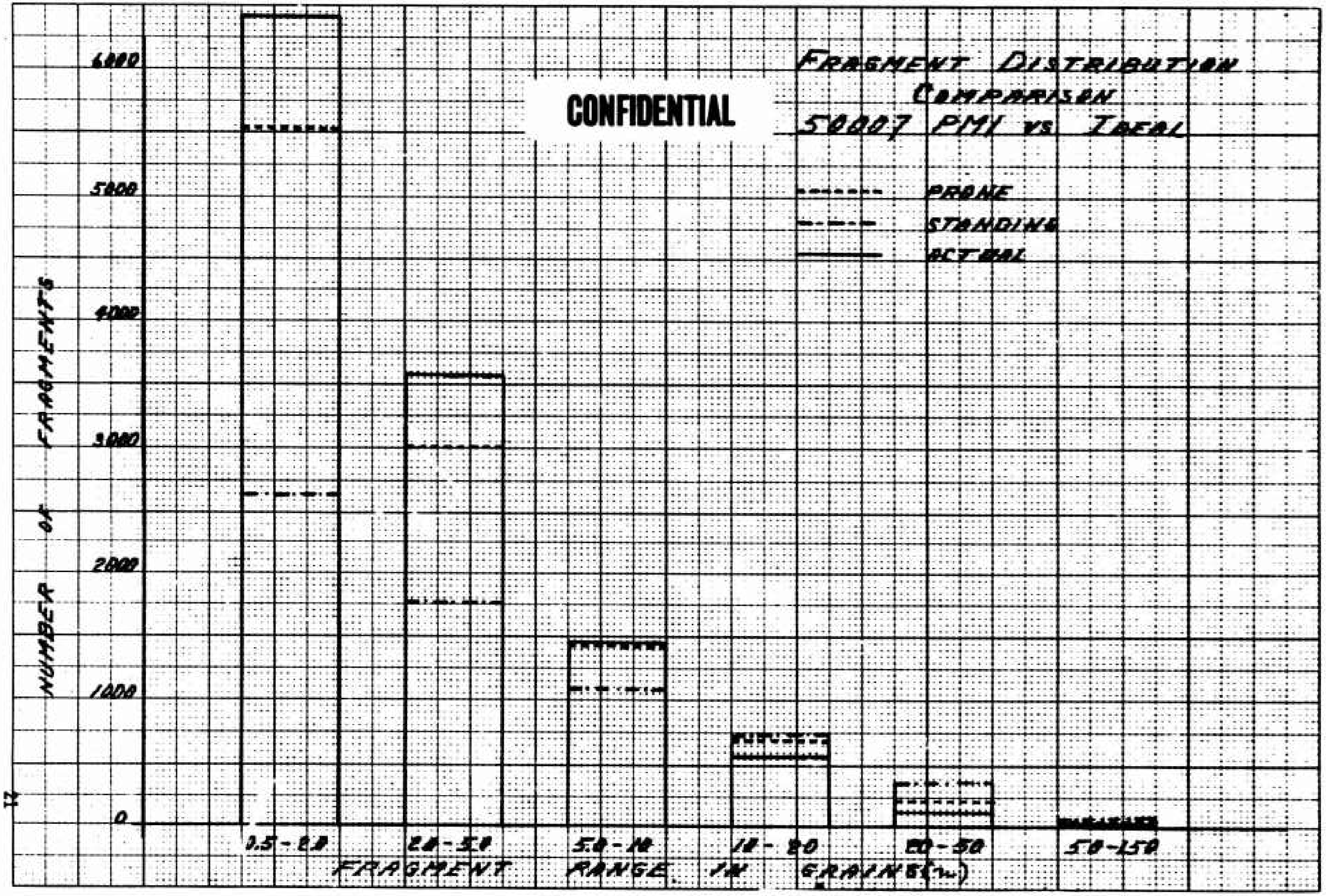


FRAGMENT DISTRIBUTION
COMPARISON
45 G10 PMI vs. IDEAL
PRONE
STANDING
ACTUAL
NUMBER OF FRAGMENTS
6000
5000
4000
3000
2000
1000
0
0.5-2.0
2.0-5.0
5.0-10
10-20
20-50
50-150
FRAGMENT RANGE IN GRAINS

GURE 4



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(C) FIGURE 5

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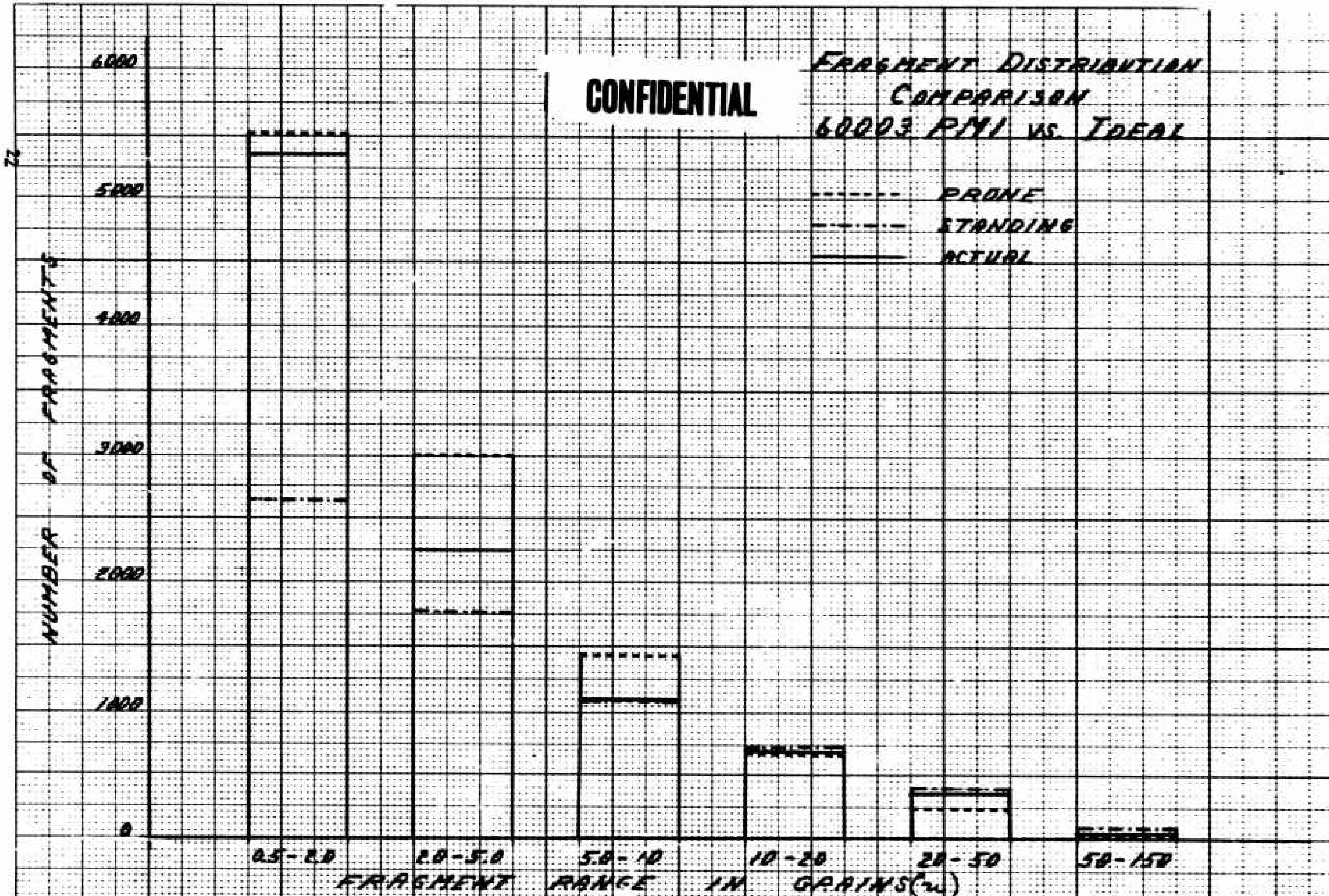

(C) FIGURE 6

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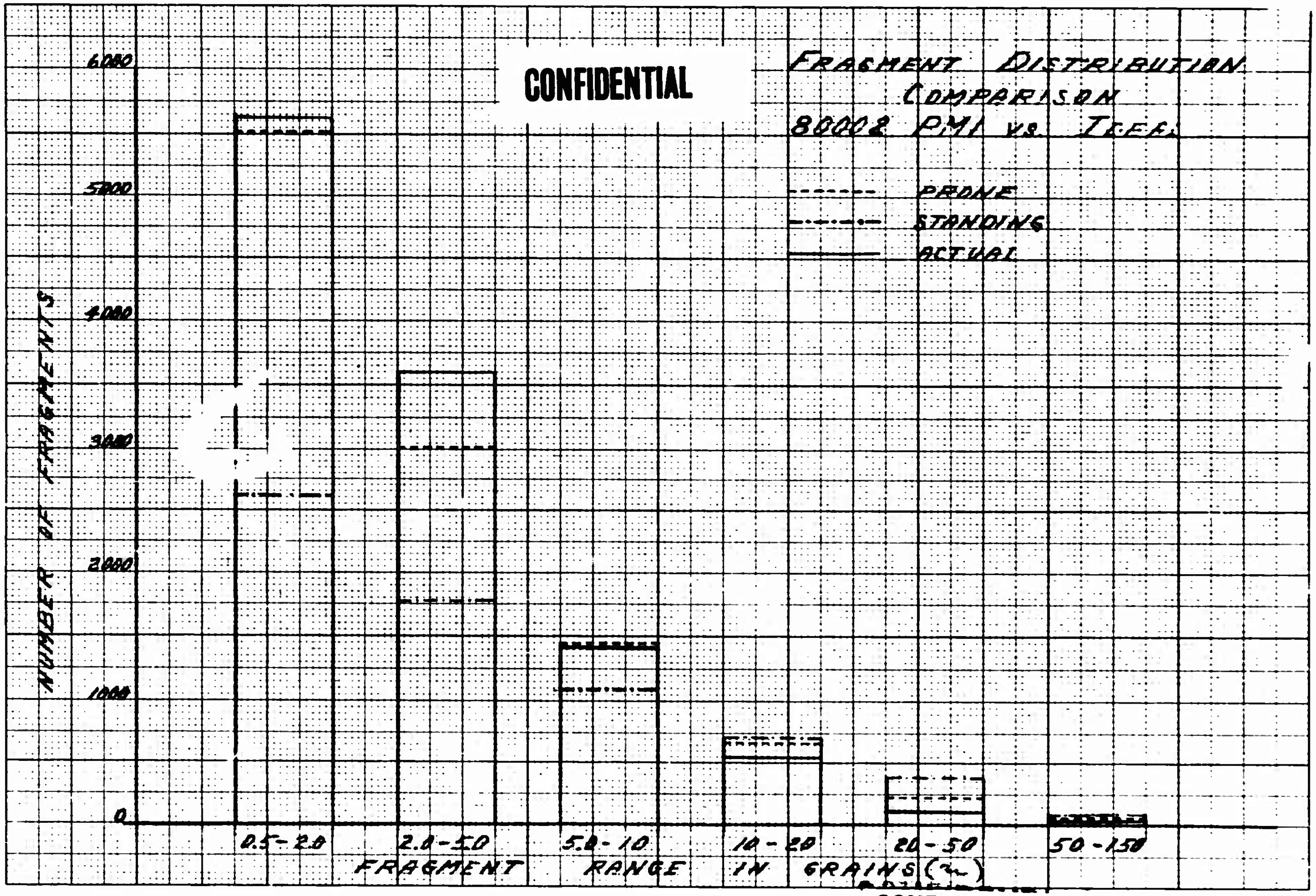

(C) FIGURE 7

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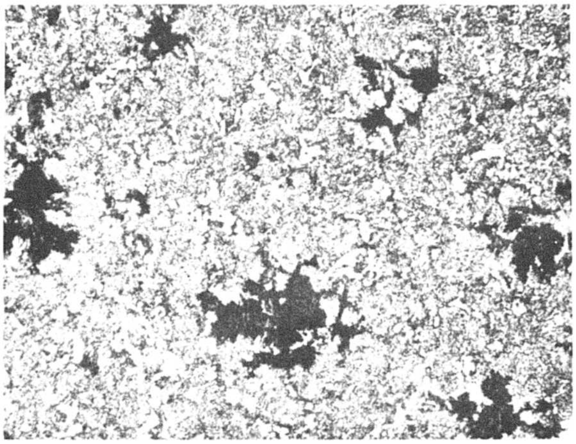

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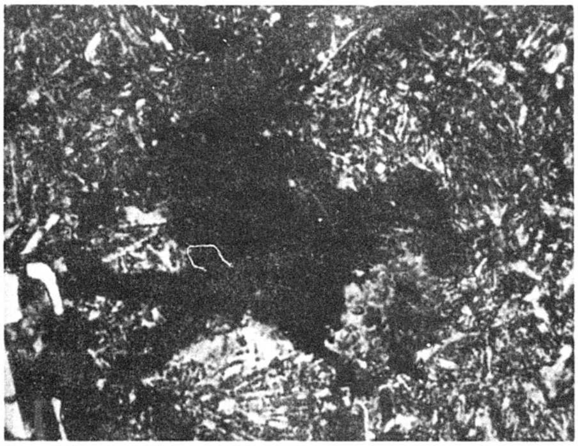

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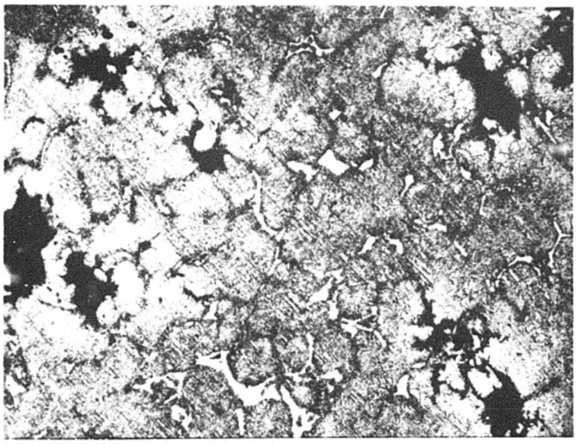
(U) FIGURE 8

MICRO-STRUCTURE OF 80002 PEARLITIC MALLEABLE IRON



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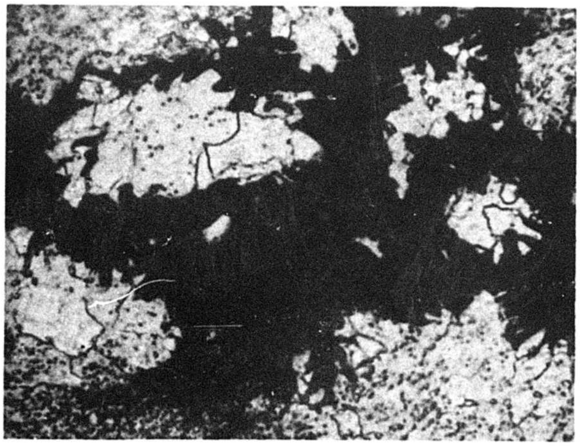

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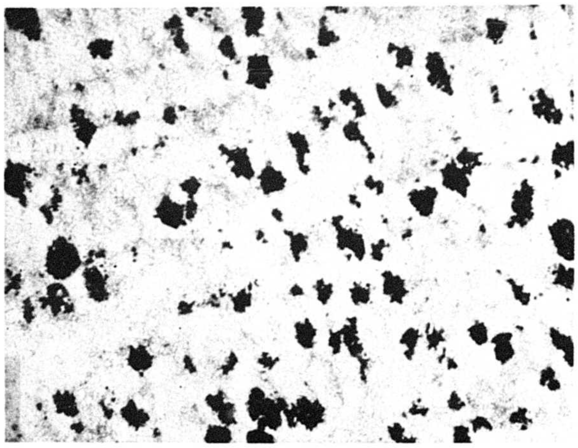
(U) FIGURE 9

MICRO-STRUCTURE OF 50007 PEARLITIC MALLEABLE IRON



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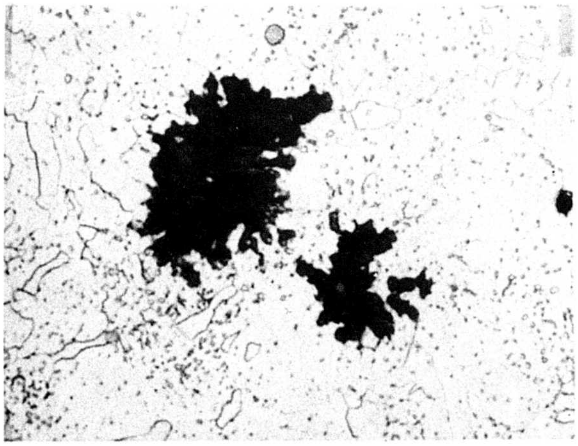

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(U) FIGURE 10

MICRO-STRUCTURE OF 45010 PEARLITIC MALLEABLE IRON

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3. REPORT TITLE

EVALUATION OF VARIOUS GRADES OF MALLEABLE IRON FOR THE 2.75-INCH M151 ROCKET WARHEAD (U)

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(Last name, first name, initial)*

KRAJKOWSKI, Edward A.
JOHNSON, Ray S.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
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13. ABSTRACT

(U) To broaden the procurement base of the 2.75-Inch M151 Rocket Warhead, ferritic malleable iron (FMI) was evaluated for its suitability as an alternate material for pearlitic malleable iron (PMI). Based on successful testing, FMI was incorporated into the Technical Data Package as an alternate material for the nose casting.

(U) Tests to evaluate the effect of matrix structure of PMI on effectiveness were run.

(U) This program for air-to-ground rocket for fixed- and rotary-wing aircraft was conducted by the Ammunition Engineering Directorate's Ammunition Engineering Laboratory.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
2.75-Inch Rocket						
Air-to-ground rocket						
M151 Warhead						
Ferritic Malleable Iron (FMI)						
Pearlitic Malleable Iron (PMI)						
Aircraft Weaponization						
Mk 1 Warhead (Navy)						
Broaden Procurement Base						
Nose Casting						
Technical Data Package						
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Fragmentation						
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